TECHNICAL REPORT # 6

From: The Crawford Hill VHF Club   Dates July 1971 (revised Oct 1986, see Additional Addendum, Oct 1986 (at end of this report).

Subjects A Water Cooled Power Amplifier for 1296 mc/s
General description,
In this report a power amplifier is described which will deliver a CW output of at least 200 watts with a total plate circuit efficiency of better than 50%, and a power gain of 10 db at 1296 mc/s. This amplifier is water cooled and employs a pair of 7289/3CX100A5 planar triodes in parallel in a grounded grid circuit with provisions for individual metering and biasing of each tube. (See addendum notes on improved biasing method)
The input (cathode) circuit is an electrical halfwave resonant line section. Approximately half of this line is in stripline with adjustable capacitive end loading for tuning and adjustable input capacitive coupling (impedance matching). The remaining portion of the halfwave resonant line is the internal structure of the 7289s. The stripline is split in such a way as to provide tight r-f coupling between tubes, but d-c isolation for individual metering and biasing.

The anode (output) circuit is a halfway cavity with the tubes plate-to-grid capacitance providing the reactive loading which foreshortens the electrical halfwave cavity to a physical length of 7.62 cm. (3 inches). The cavity can be considered as a section of reduced height, beyond cut-off rectangular waveguide with the tubes in the transverse plane. Tuning is accomplished by means of a sliding plunger on one side of the tubes, and output coupling is provided by an inductive coupling loop and coaxial line which protrudes through a fixed wall on the opposite side from the tuning plunger. Output loading (impedance matching) is obtained by rotating the coupling loop and moving the anode plunger.
The amplifier is constructed of standard brass bar, plate and sheet stock, and may be fabricated with a minimum of machine work. Since the resonant circuits are relatively low-Q, little improvement in performance can be obtained by silver plating. However, silver plating will enhance the appearance and greatly extend the life of the amplifiers

Water Cooling System

The water cooling system employed with this amplifier is a closed circulating system which NEVER permits the water to boil in the anode jackets. While this system is less efficient in extracting heat, it DOES provide the lowest operating temperature which is considered more important in this case. In addition, this closed system permits direct evaluation of power output by simple calorimetric means, as described in Technical Report * 7.
Each tube is fitted with a semi-permanent water jacket as

shown by Figure 4. The jacket has two water connections which permit the jackets to be attached to the water reservoir and pump by means of 3/8 inch I.D. (inside diameter) plastic tubing as indicated in Figure 1.
The series connected water jackets maintain equal flow in each jacket and with reasonable flow (1/2 gallon per minute minimum) the differential temperature between the tubes will be negligible.

Distilled water should be used and a reservoir of 1 to 2 gallons should be adequate for intermittent amateur service. Sufficient flow rate can be easily obtained from a small fish tank or fountain pump.* Since the anode water jackets are at high voltage potential, it IS NECESSARY to provide a protective ground for the water supply and pump. This is provided for by two short metal nipples inserted in the water lines and grounded to the amplifier ground system (see Figure 1.). A minimum of one foot (30 cm.) of plastic tube should be allowed between the tube water jacket and nipple in each line. The d-c resistance of distilled water in a 3/8 inch I.D. clear vinyl tubing is about one megohm per foot. The nipples also provide a convenient disconnect point for the water supply when maintenance is necessary and should be located physically with the amplifier. Should water leakage current exceed 5 ma., as indicated by the anode current meters with H.V. applied but no heater current to the tubes, this indicates that the water has become contaminated. The system should be flushed and a new supply of distilled water installed.

The amplifier should NEVER be operated without water flow. Although no flow interlock device is shown, some means of indicating flow should be used. A simple visual device may be constructed as shown in Figure 1, and consists of a brightly colored thread or ribbon secured to a pin which is inserted diametrically through a rigid plastic nipple. If the device is. placed horizontally, flow will be indicated by movement of the ribbon while lack of flow is indicated by the ribbon settling to the bottom of the nipple and remaining stationary.

A suitable reservoir may be made from a variety of readily available plastic containers. Choose one with flat sides so that tubing connectors may be installed with minimum trouble. Also choose one which can be closed or has a cover to prevent external contamination. Do NOT use metal or some plastics, such as Plexiglas which is hygroscopic and will eventually warp when in contact with water. With a metal reservoir, electrolysis and corrosion will contaminate the water.
It will be necessary to purge the system initially to clear all air from the lines and jackets, and it may be necessary to repeat the purge operation after long idle periods. Pinching the flexible tubing where air pockets occur, with the pump running, will remove most of the air.

* Consult supply catalogues, Sears Roebuck and Company for one.

Construction Details
All important dimensions and most construction details should be self—evident from the drawings. While substitution of materials may be made, the important inside dimensions shown should be adhered to carefully.

When soldering in the finger stock it is advisable to first form the stock into rings to fit the hole size and then use a 'dummy' tube or an equivalent size aluminum rod to hold the finger stock in place while soldering. Install finger stock last and use a minimum of heat as the stock material may be annealed with too much heat, resulting in poor contact with the tube rings. If a substitute grid finger stock is used, no guarantee can be made that the anode circuit will resonate at 1296 mc/s since the physical shape immediately adjacent to the tube can change the reactive loading.
Note that NO finger stock is required at the anodes.The resonant quarter wavelength anode chokes MUST use Teflon for a dielectric in order to maintain the correct electrical length.
About 1/16 of an inch of the dielectric should be allowed to protrude into the anode cavity,
and about 1/4 inch above the top of the outer cylinder. The Teflon is wrapped tightly around the water jacket as shown in Figure 5, and then the assembly is carefully slipped into the outer cylinder.

Special care should be observed to see that ALL tube rocketing details are in good coaxial alignment so that no undue transverse farces are applied to the tubes when they are in place. A locking arrangement at the top of the water jackets forces the tubes down into the amplifier securely.
It is recommended that all parts which will be initially secured together, be sweated together permanently. This includes the basic parts shown in Figure 3, and also the complete anode cover plate. In this way the critical areas of high r—f current will be assured of good electrical conductivity, especially in the anode cavity immediately adjacent to the tubes.
The various pieces should of course be fitted together before sweating to check and correct alignment and surface warpage. The grid ring finger stock should be installed last as indicated previously and with minimum heating. It has been found that in some amplifiers, poor anode circuit efficiency has been-traced to loss of tension in the finger stock at the grids and thus poor electrical conductivity. This can be caused by over heating during installation, or from insufficient cooling during long periods of operation.

After sweating together all the basic parts and fabricating the remaining parts, the entire amplifier should be completely disassembled and thoroughly scrubbed, including the tubes, with a stiff brush, detergent soap and water. Each part should be carefully clean dried with absorbent towel and air blast where
necessary.

Be sure that all traces of solder flux and rosin are removed especially from inside the cavities. Round off all corners and sharp edges in the r—f resonant sections especially before the cleaning operation for electrical and personal safety. The heater chokes which are quarter wavelength resonant stubs are simply a means of physically supporting the heater chuck with

negligible r-f disturbance to the cathode tank circuit. Other means may be used to support this chuck physically, and a simple wire wound RFC can be used for r-f decoupling. Although adequate cooling of the anodes is provided by the water circulating system, the grid and cathode tube seals must be cooled. This is provided for by a small blower which forces air through the 3/8 inch holes in both the cathode and anode side walls on one side of the amplifier and exits the air through similar holes on the opposite side. A plenum between blower and air holes would be highly desirable for efficient use of available air flow.

In the water tubing system it may be desirable to have sharp bends in the flexible tubing. Most non-rigid tubing may be permanently bent into sharp radius curves without sacrifice of cross sectional area by the following method. First pack the section of tube to be bent with fine sand. Next, gently and uniformly heat the section to be bent on a heater or open flame. Do not overheat and check a small sample of the tubing for combustion hazard. When the material becomes noticeably softened while rotating and moving the section over the heat source, remove from the heat and quickly make the desired bend slightly less in radius than desired. Finally cool the section under running water while holding the shape.

Remove and flush out the sand.

No mounting details are given here for this amplifier as individual circumstances and needs will suggest these details. There is no restriction in mounting position for this amplifier, as long as air pockets are removed from each water jacket.

Tuning and Operation

Initial adjustments of this amplifier are similar to any new amplifier that is they should be done with caution and perception at reduced voltages and power level. Apply about 500 volts to the anode, circulating water and sufficient bias to permit 10 to 30 ma of idling anode current on each tube. Have some termination (50 ohm) for the amplifier to dissipate r-f power into, such as a dummy load or antenna fairly well matched and aimed away from all living things.

Next apply sufficient drive to raise the anode current to about 50 ma. per tube and attempt to tune the anode cavity to resonance. The output link coupling should be in position of nearly minimum coupling (plane of the loop parallel with top cavity wall is minimum coupling). The usual sharp dip in anode current should be observed as an indication of cavity resonance at about midrange of the tuning plunger.

If the dip is not pronounced it may indicate faulty construction of the anode cavity which will greatly reduce the Q of this tank. Resonance at the extreme end of the tuning plunger range usually indicates that the cavity dimensions, tube seating or finger stock placement is not correct. A moderate correction in anode resonance can be achieved by moving the cavity wall which is opposite the plunger. It is advisable to initially secure this wall by means of two 'C' clamps and adjust its position so that the tuning plunger will resonate the cavity at midrange of the plunger extremes.

Next check the cathode line resonance to see that it can be obtained at a reasonable point in the tuning range of the disc capacitor. This resonance is quite broad and can be observed by peaking of the cathode currents at resonance. When resonances have been established, anode voltage may be increased and input and output couplings adjusted for maximum power output. Be sure to check both input and output resonance tuning with each change in coupling.

At full anode voltage and bias, no anode current should flow when drive is removed. When full operating conditions are reached with r-f drive, the cathode bias on each tube may be trimmed so that each tube draws about the same anode current. Depending on the condition of your tubes, the final operating conditions will be approximately;

Eb = 2000 volts (d-c)

Ib 125 ma. (per tube)

Ik = 150 ma. (per tube)

Ekg = 45 volts (zener resistor bias) per tube

Po = 250 watts (r-f)

Pin anode d-c = 500 watts

Pdrive r-f - 25 watts

Under these conditions and properly adjusted, the water in the tube jackets should not boil. Onset of boiling is indicated by a 'popping' sound in the jackets. Off resonance anode tuning or over coupling at the output can cause sufficient inefficiency which may cause boiling.

Although this amplifier has been operated with cathode current in excess of manufacturers maximum ratings (125 ma. per tube), which will probably shorten tube life, it is felt that for intermittent amateur service especially in the keyed telegraph mode, the strain on the tube may be justifiable.

No attempt has been made to modulate this amplifier or check its linearity at full power. At reduced levels the amplifier will deliver 100 watts output with 1000 volts on the anode and about 20 volts bias. Under these conditions tube life should be according to manufacturer’s specifications and the amplifier may be high level modulated for AM service.

Precautionary measures should be taken with tubes of the 7289 type to limit peak anode current in the event of internal flashover. A 300 ohm 25 watt resistor between the amplifier and 2000 volts supply is adequate to limit the peak current to about 6 amps with a loss in anode voltage under operating conditions of about 100 volts. In addition, a high voltage type fuse is recommended to prevent burn out of the current limiting resistor or the primary of the anode supply transformer may be fused to just above operating conditions.

This amplifier, as with any grounded grid amplifier, can become unstable without output loading. It is highly recommended that in station operation the antenna switching relay and high voltage control relay be sequenced or interlocked in such a way as to prevent the amplifier from having high voltage without r-f load at any time and especially during switching.

It is also possible for this amplifier to become unstable (oscillate) at lower r-f due to external leads in the cathode and anode returns. This latter type instability may be suppressed by suitable resistors and by pass capacitors external to the 1296 mc/s circuitry. A suitable suppressor is shown by Figure 1. and is highly recommended.
The by-pass capacitors are high voltage mica (Sangamo). In addition, VHF parasitics may appear as a result of cathode RFC resonance. Should this occur, the cathode RFC may be altered to more or less turns. Little effect should be noted at 1296 mc/s for large variations in the size of this choke.

Remarks
The original design of this amplifier was by W2CCY in • convection water cooled form and later modified by W2CQH to an air cooled design which was published in March 1970 HAM RADIO magazine, page 43. The circulating water cooled system was suggested by K6MYC, and the amplifier described here was built and measured by W2IMU and the Crawford Hill VHF Club.
Some versions of the 7289 tube have screw-on air cooling fin assemblies rather than the split collar and set screw arrangement. The former may be separated from the tube by first filing or machining away the bottom fin which is adjacent to the top of the anode cup.

This will release the strain on the threading and the fin assembly may be unscrewed easily (right hand thread).
Two amplifiers may be combined in parallel by means of quadrature hybrids (Tech. Report # 2) to obtain 500 watts output for EME application. See also Technical Report #19.

Addendum (August 1973, revised Oct 1986)
It has been several years since this water cooled amplifier was built and some additional experiences have since been gained.

Although water cooling does permit higher anode dissipation to be achieved, the high power limit of the 7289 type tube may be fixed more by grid dissipation. It is therefore stressed that extra air flow at the grid finger stock be employed. One way to achieve this is by using the anode cavity as a pressurized plenum forcing air to pass through the grid finger stock and exit into the cathode enclosure. This method requires a better blower than indicated previously.
Excess grid dissipation is caused by over driving as well as a lossy anode cavity, incorrect tuning and loading of the anode cavity. An indication of a faulty anode circuit is when anode current 'dip' and maximum power output are not coincident with anode tuning.

Tube failures will occur when excessive grid dissipation is present by physical warpage of the grid screen mesh, eventually causing a grid-to-anode or grid-to-cathode short circuit.
Grid warpage due to excessive dissipation and or poor cooling of the grid ring is also evident by drift in anode circuit tuning as the amplifier runs.

Should any of the above effects be noted, the amplifier should be dismantled and examined carefully for faulty construction or materials.
The water system will contaminate over a period of a year or so. Contamination accelerates electrolysis and damages the anode cup and pinch-off tube in the cup.If allowed to persist, the metal wall may actually puncture with catastrophic results. Electrolysis may be slowed down by changing the distilled water frequently and increasing the hose length between amplifier and grounded water reservoir.

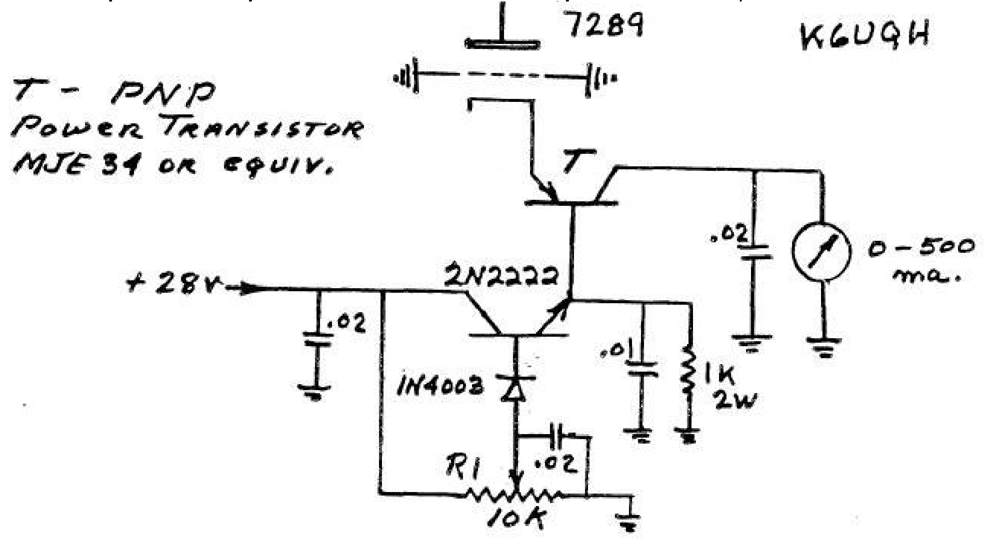
The cathode stripline resonator which includes a d-c blocking capacitance may be fabricated from 1/16 inch thick double sided copper clad Fiberglass printed circuit board. Using the Fiberglass as a dielectric, the part is made essentially with the same dimensions as the original shown by Figure 5. The copper may be either etched away at appropriate places with suitable masking, or may be removed mechanically by scraping or peeling. Since the resonator is low-Q, the dielectric losses should be negligible here.

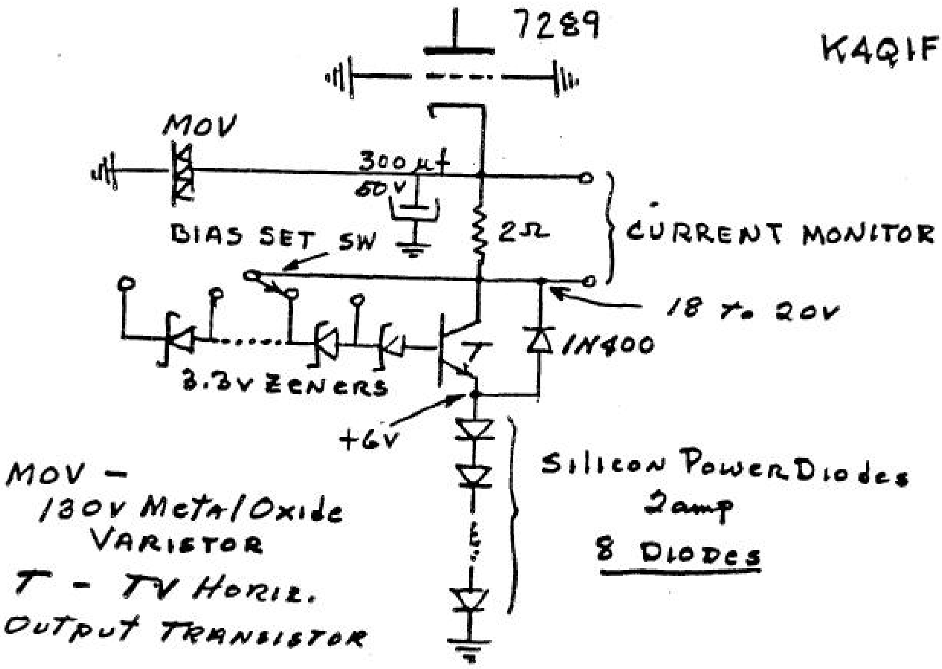
Additional Notes (November 1986)
Additional experience and information now available indicates that water cooling has gained favor amongst EME enthusiasts. Numerous designs have emerged to modify the 7289/3CX100A5 for water cooling which are easier to fabricate that the type shown in Report M 6. See the K2UYH "432 mc/s and Above" newsletter technical section (1985-6) for some designs.

7

A great improvement in the power output can be obtained from recent developmental work by N6CA, K6UQH and members of the Eimac Company.
The modification is to replace the zener/resistor cathode bias arrangement with an electronically regulated d-c cathode bias supply. This very "stiff" bias voltage supply permits much higher peak anode current in the tubes which results in a power output increase of at least 2.
The attached Figure shows one version of this cathode bias regulator for use with the two tube amplifier.
*** See QST March-April 1985, " A Quarter-Kilowatt 23-CM Amplifier***

Improved cathode bias for grounded grid power amplifiers using planar triodes of the 7289/3CX100A5 type.
The upper circuit suggested by K6UGH requires • +28 volts low current supply to bias the regulator circuit. The potentiometer, Rig adjusts the cathode current level.
The lower circuit suggested by K4QIF requires no additional supply and is adjustable in steps of 3.3 volts.
Each 7289 tube requires a separate cathode bias regulator circuit, as shown here.





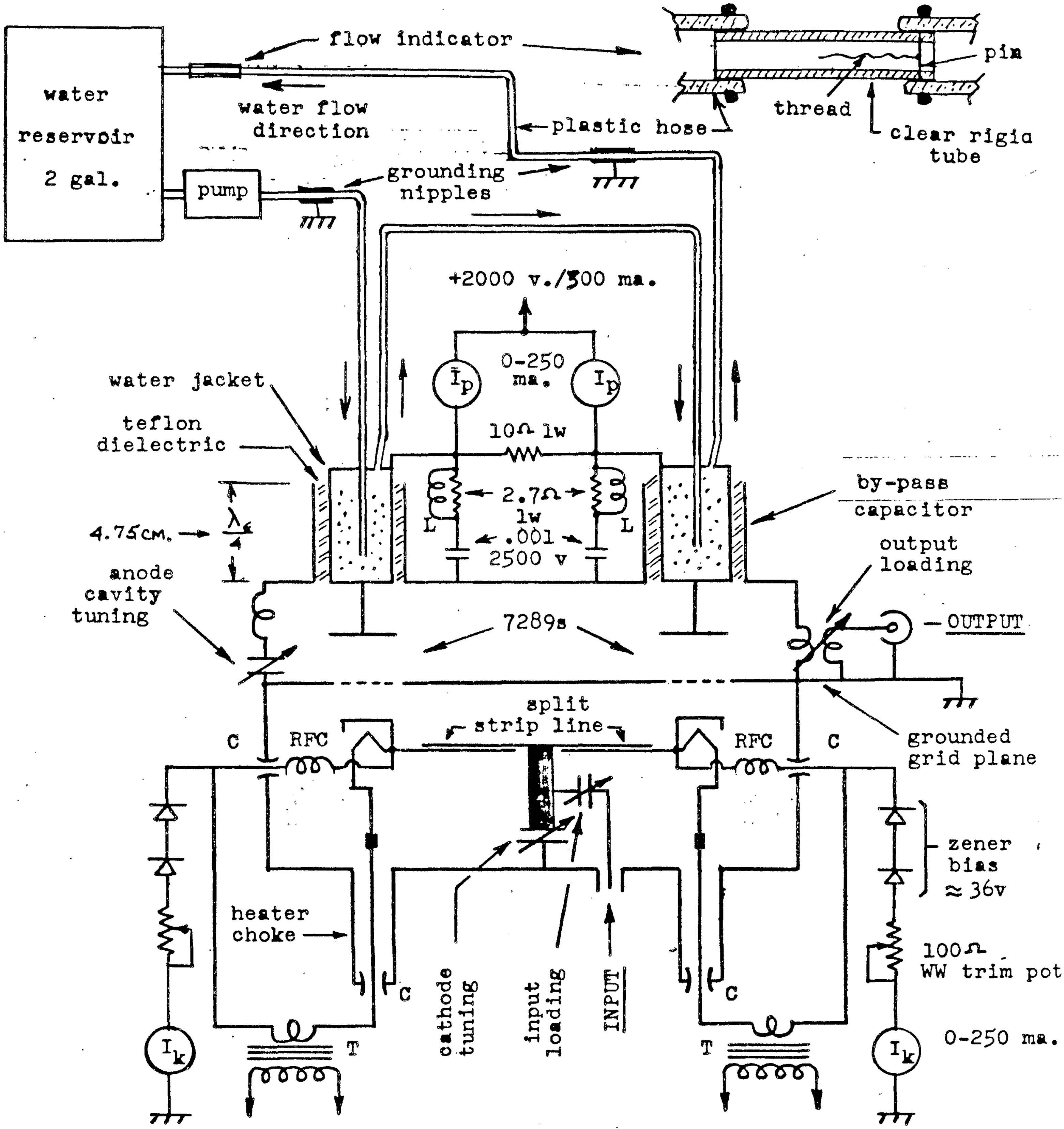


Figure 1. Electrical schematic and water system diagram of the dual 7289/3CX100A5 grounded grid power amplifier for 1296 mc/s. RFC is 6 t #18 Formex air wound on 1/8 inch diam. L is 3 t #22 wire wound directly on the 2.7 ohm 1 watt composition resistor. C is 500 pf feedthru capacitor. T is heater transformer 6.3 v at 1 amp.

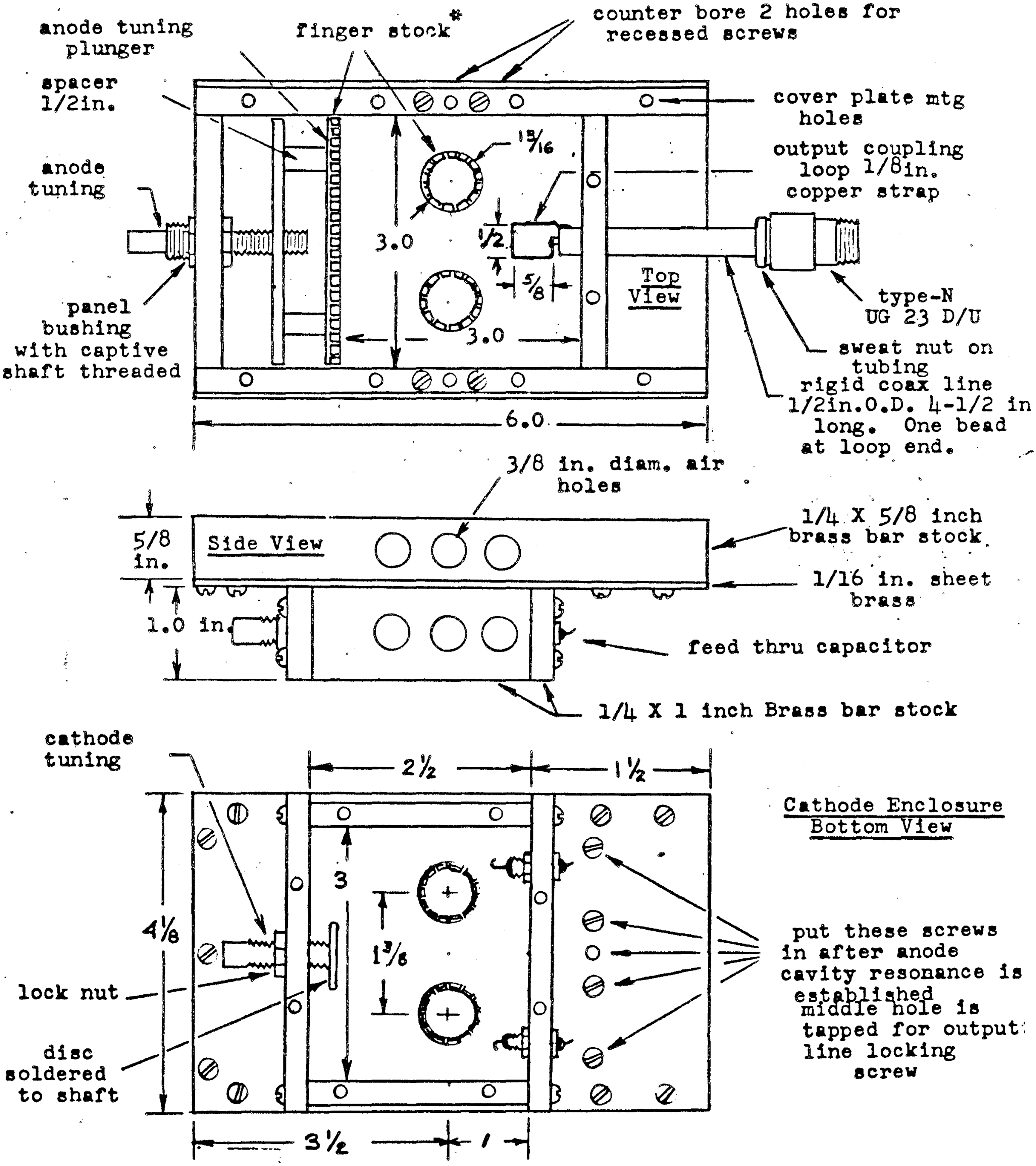


Figure 2. Detailed views of amplifier without top and bottom cover plates. All dimensions are in inches.

* All finger stock is Instrument Specialties Co. part # 97-251 Little Falls, New Jersey or equivalent.

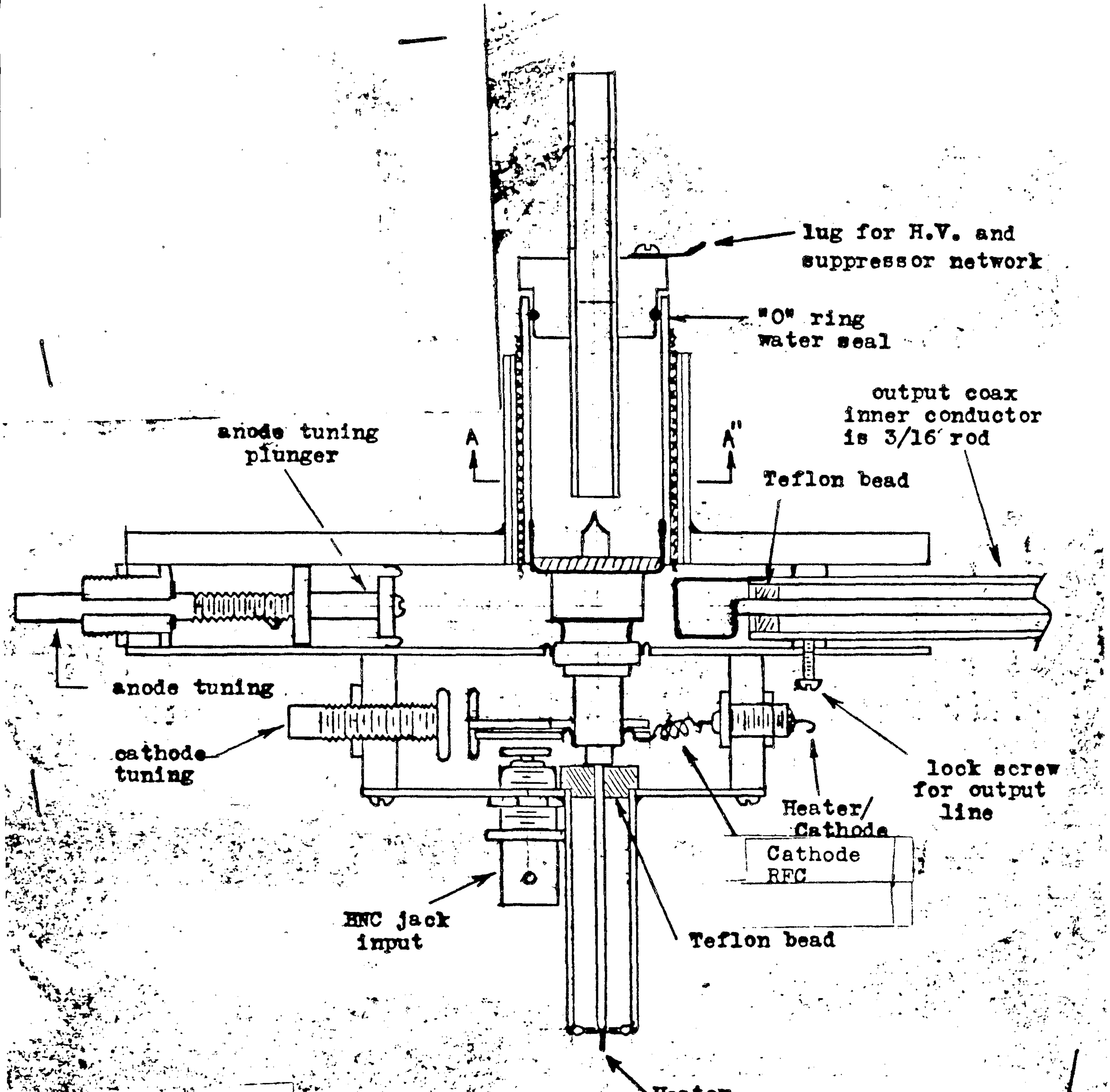


Figure 3. Exposed side view showing assembly details. See other drawings for dimensions. This drawing is approximately full scale.

The dielectric in the coaxial by-pass capacitor consists of sheet teflon, 0.001 to 0.005 inch thick, tightly wound around the water jacket to fill the space between the cylinders. There is about 0.030 inch of space to be filled as completely as possible. A small tab of clear Scotch tape may be used to secure the inner end of the teflon tape to the water jacket for winding convenience.

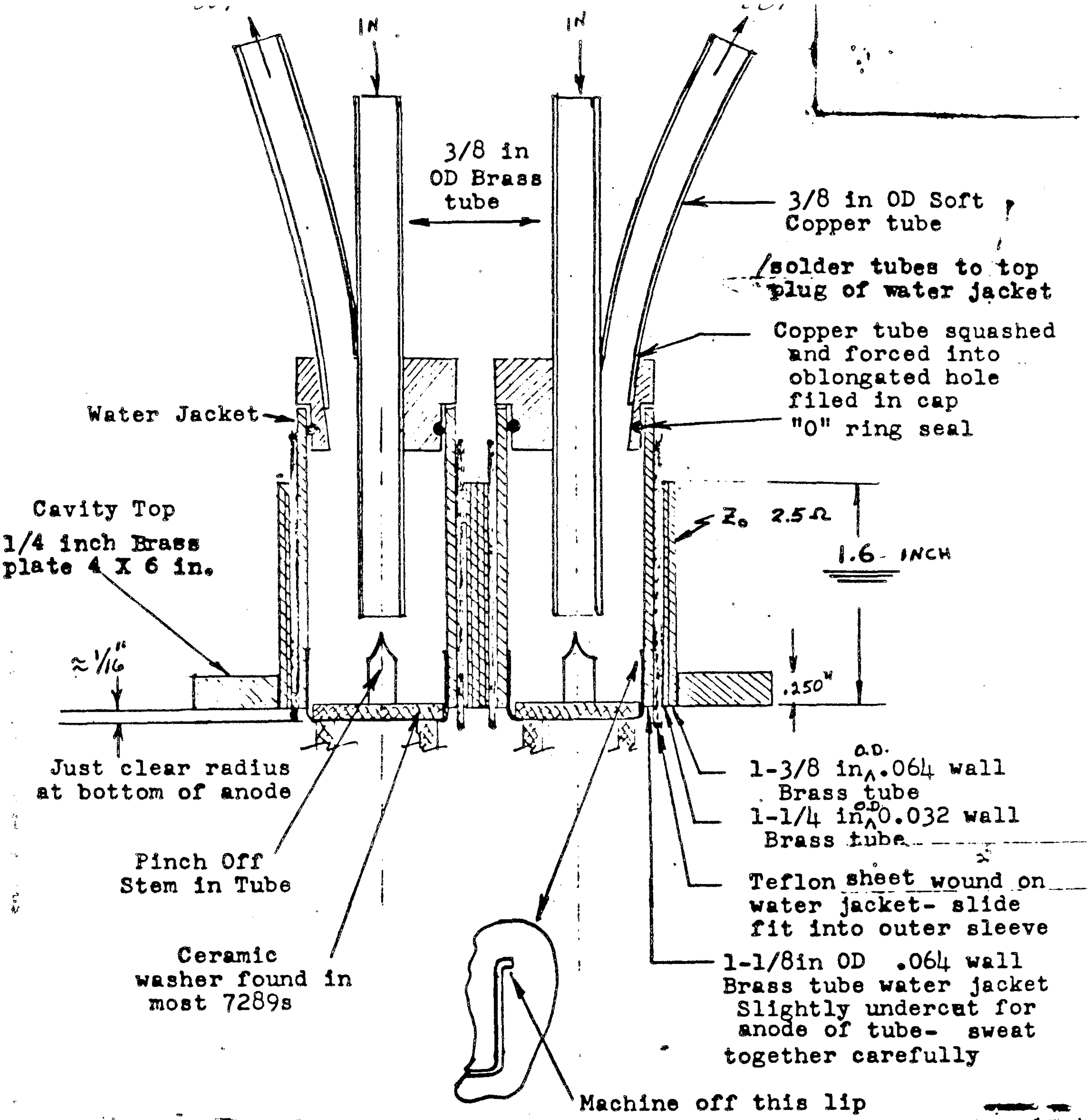


Figure 4. Cross sectional view of water jacket assembly and resonant coaxial by-pass capacitor. Standard brass tube is indicated for convenience. The 1-3/8 and 1-1/4 inch O.D. tubes are forced together and soldered.

The water jackets are soldered directly to the anode cups of the 7289s. The lip at the top of the anode cup on most tubes should be carefully machined or filed off. Bring the jacket with tube inserted slowly up to temperature on a hot-plate, solder, then allow to cool very slowly to avoid straining the ceramic to metal brazed seals of the tubes. A piece of aluminum foil wrapped around the ceramic part of the tube will prevent contamination of this area by flux splatter during soldering.

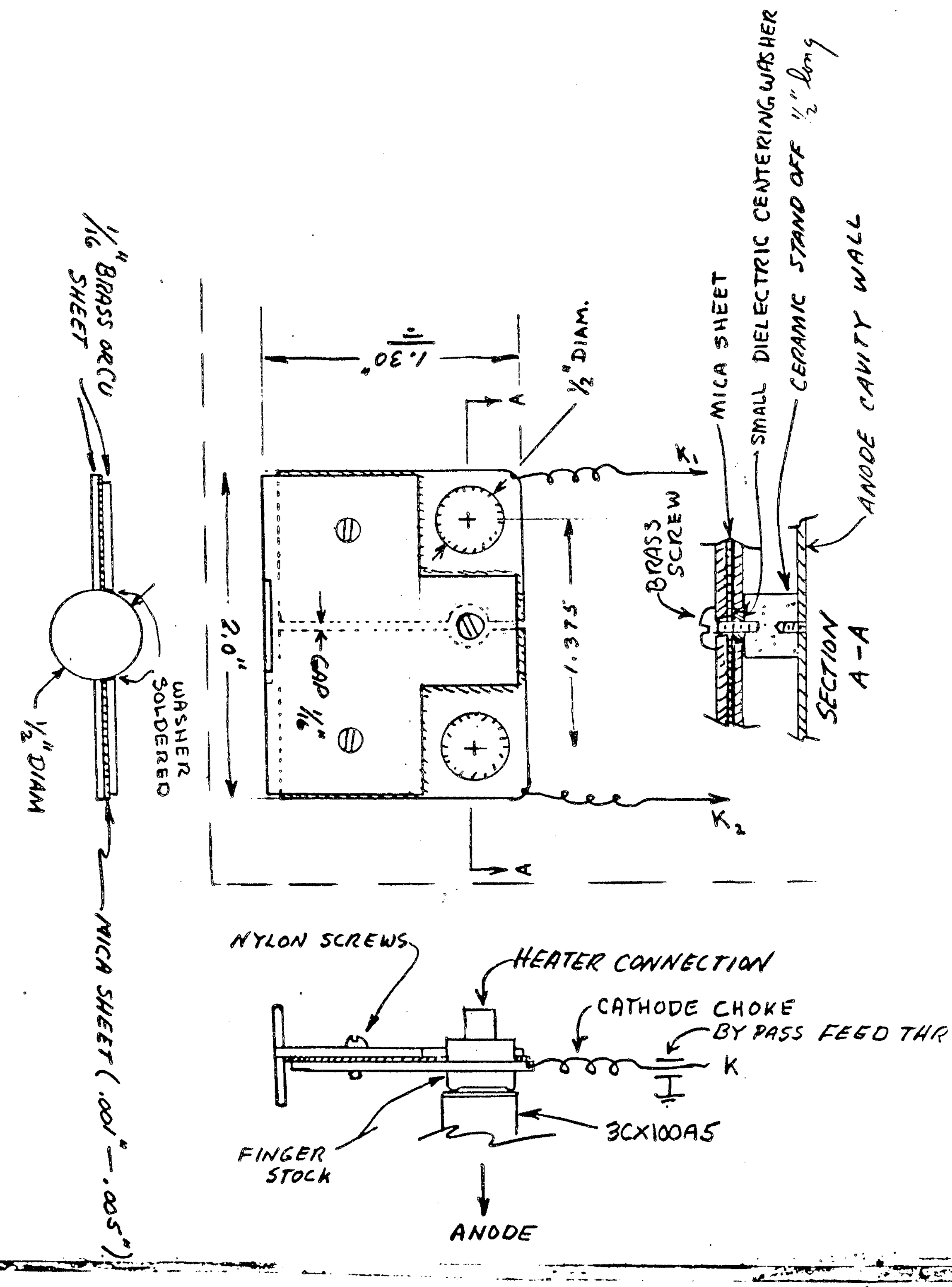
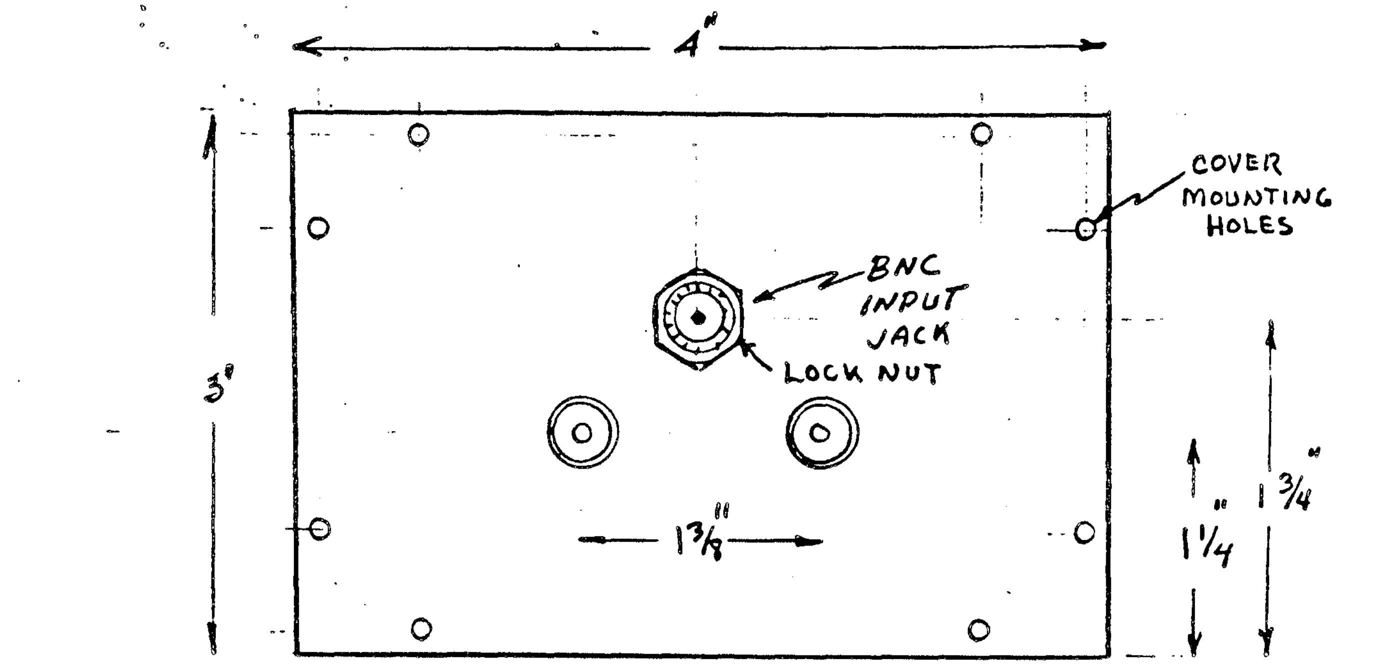
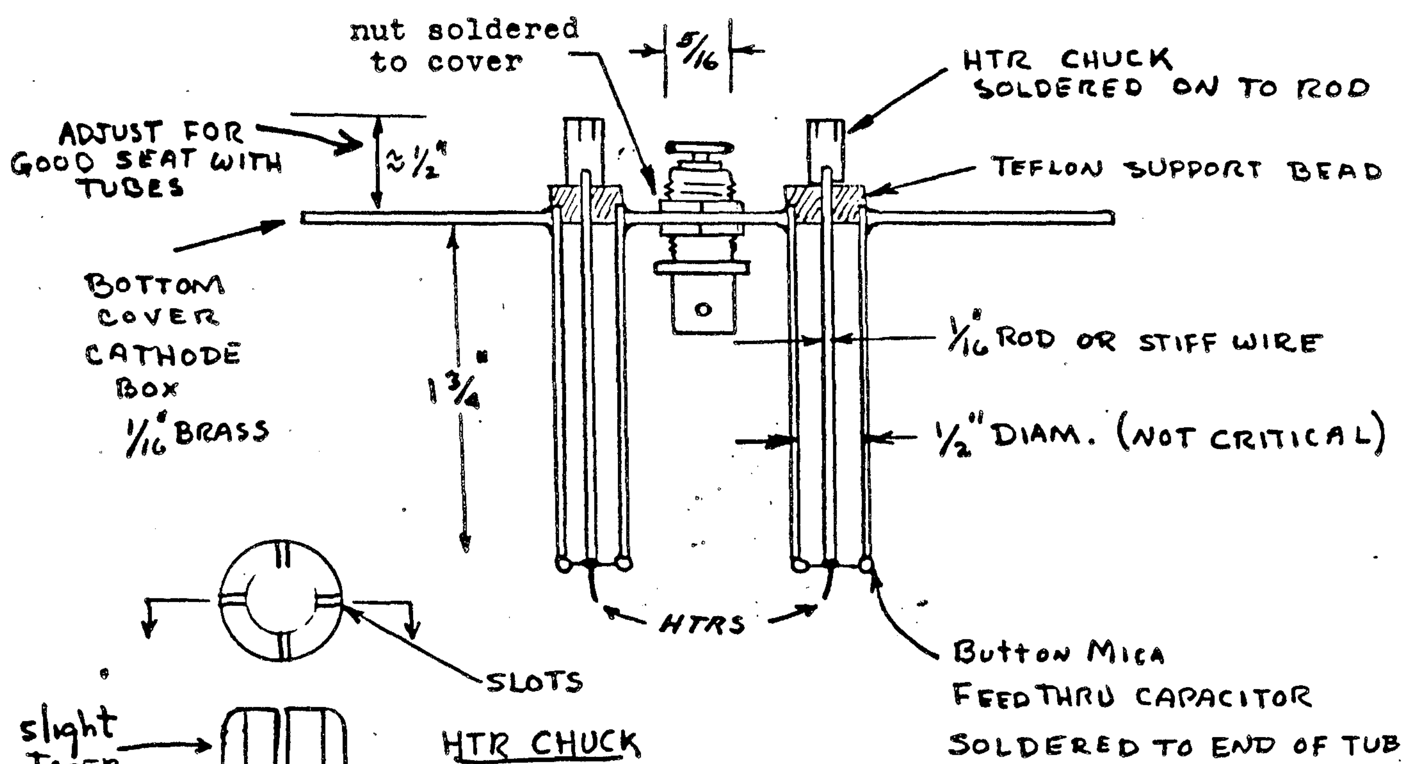


Figure 5. Cathode strip line details. The line is split down the center to permit separate biasing and metering of the two tubes. All dimensions are in inches. Mylar may be substituted for the mica dielectric. The line sections should be very flat so that maximum capacitance occurs in the dielectric sandwich.





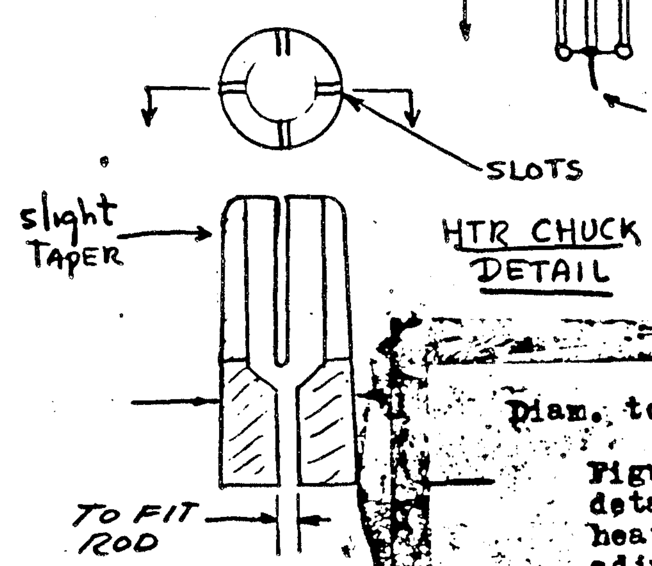


Figure 6. Cathode enclosure cover showing details of quarter wave heater chokes and heater chuck detail. The input coupling is adjusted by means of the threaded BNC jack. A lock nut is used on the outside and a similar nut may be soldered to the inside of the cover plate, or the plate may be tapped 3/8-32.